SCIENCE FOR CERAMIC PRODUCTION

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HIGH-POROSITY MULLITE-SILICA CERAMICS

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Two types of highly porous mullite-silica ceramics are considered: ceramics with fibrous and granular structures. The main properties of the materials are given and application areas are identified.

The granulometric composition of mullite-silica glass fiber is represented by the proper fiber and nonfibrous rounded formations (globules) [1]. The content of these globules reaches 70% of the total material. The possibility of using the fiber component for reinforcing metal was demonstrated earlier. The obtained results indicate that the properties of the materials in the fiber – metal system surpass the properties of metals and that parts made from such composites are capable of operating in more rigid conditions than metallic parts.

The present study investigates some issues related to the production and properties of ceramics made of fibrous and nonfibrous components of the initial glass fiber of mullite-silica composition.

Ceramics based on the fibrous component were produced by adding binders of a specially selected composition, then the samples were molded from the aqueous suspension and fired. Ceramics based on the nonfibrous component were obtained by semi-dry molding and subsequent heat treatment.

The parameters determined in the course of the study include the bulk density of the fiber and the globules, the size distribution of the globule particles, the shrinkage of ceramic samples in heat treatment, the bulk density and open porosity of ceramics, the compressive strength, the permeability coefficient, and the thermal conductivity.

Pore-free discrete fibers which are initial materials for the formation of ceramic structure have a diameter of 2 – 4 μm with controlled length from 50 to 2500 μm. The bulk density of fibers varies depending on their length from 0.10 to 0.37 g/cm^3 (Fig. 1). As the fiber length decreases, i.e., as the fiber shape becomes less asymmetric, the packing density of freely poured fiber increases. At the same time, until the fiber length reaches 120 μm, the bulk density varies but little, and with a length below 120 μm, the dependence of bulk density on the fiber length becomes more evident.

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The nonfibrous component is represented by virtually pore-free particles of a rounded shape which are called globules. The particle size ranges from 10 to more than 400 μm. The sizes of most globules fall within the range of 63 – 200 μm. The content of such globules is up to 60% of the total quantity. The bulk density of the globules depending on their size varies within the limits of 0.96 – 1.40 g/cm^3.

It is evident that the properties of ceramics depend both on the properties (sizes) of the globules and on the conditions of ceramic production.

In making fiber-based ceramics, the fiber size and the molding pressure varied, and in making globule-based ceramics, the variable factors were the fiber size and the sintering temperature. These parameters are the most significant in order to reach the required apparent density (open porosity) in fibrous ceramics, which, in turn, determines the fiber concentration in the future fiber – metal composite. Furthermore, the effect of the binder content on the strength of ceramics was estimated as well.

As the fiber length decreases, the apparent density of ceramics increases. The dependence is linear and the apparent density grows from 0.27 g/cm^3 for a fiber length of 250 μm

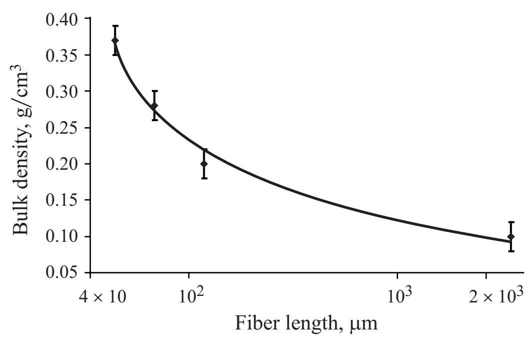

Fig. 1. Dependence of bulk density of fiber on fiber length.

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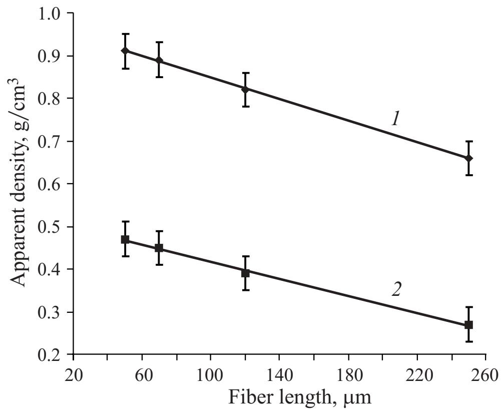

Fig. 2. Dependence of bulk density of ceramics on fiber length with molding pressure 0.1 (*1*) and 2.0 MPa (*2*).

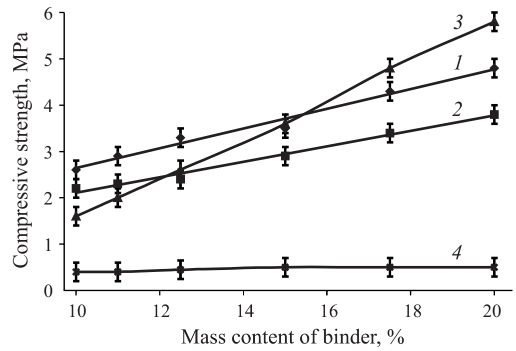

Fig. 4. Compressive strength depending on the binder content: *1* and *2*) local strength parallel and perpendicular to the molding direction, respectively; *3* and *4*) integral strength parallel and perpendicular to the molding direction, respectively.

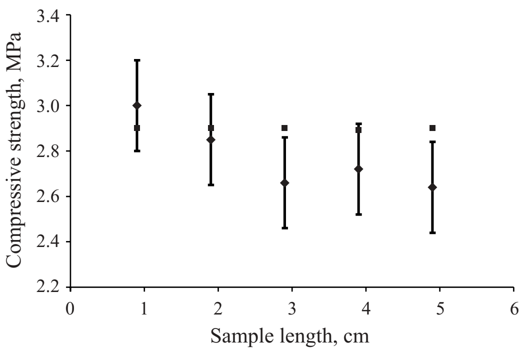

Fig. 3. Distribution of local compressive strength (parallel to the molding direction) with the binder content 11 wt.%: ♦) strength; ■) points of load application.

to 0.41 g/cm^3 for a fiber length of 50 µm (molding pressure of 0.1 MPa). An increase in pressure up to 2.0 MPa makes it possible to produce ceramics with an apparent density of 0.65 – 0.90 g/cm^3 (Fig. 2).

Thus, variation of the condition of preparing ceramics makes it possible to modify the bulk density within wide limits from 0.27 to 0.90 g/cm^3, which correlates with an open porosity of 90 – 72%.

The compressive strength was determined on samples with a bulk density of 0.27 g/cm^3 by applying a load to the total areas of their opposite surfaces (integral strength) and also based on the depth of penetration of the indentor (local strength). The measurements were carried out in two directions: parallel and perpendicular to the sample molding direction.

The measurements of local strength in samples cut out from the central part of a disk 120 mm in diameter and 35 mm high show that the strength depends little on the point of its measurement (Fig. 3). This is evidence of the uniform distribution of the binder over the total volume.

It is interesting to correlate the measurement results of the integral and local strength determined in different directions. Thus, the local strength increases linearly with increasing binder content and varies little depending on the direction of its determination (Fig. 4). At the same time, the integral strength in the direction parallel to molding significantly exceeds the strength in the perpendicular direction. Furthermore, although the integral strength has a perceptible linear dependence on the binder content when registered parallel to the molding direction: tangent 0.48 (Fig. 4, curve *3*), the perpendicular strength depends little on the binder content: tangent about 0 (Fig. 4, curve *4*).

The ratio between the values of local and integral strength perpendicular to the molding direction is somewhat unexpected: the local strength of ceramic is significantly higher than the integral strength. Apparently, such ratios between the strength values are due to anisotropy of the structure of samples arising due to some orientation of the fibers, which emerges in molding of ceramics.

In this context one should expect anisotropy of other properties of ceramics. Indeed the thermal conductivity of ceramics with bulk density 0.27 g/cm^3 perpendicular to the molding direction is 0.12 W/(m · K) and in the direction parallel to the molding direction it is 0.07 W/(m · K). At the same time, the water permeability does not depend on the direction of measurement and is equal to 5.5 µm^2.

To account for isotropy of some properties of ceramics and anisotropy of others, its structure and the effect of technological factors ought to be investigated in detail.

The shrinkage curves of samples based on the globules exhibit the first shrinkage segment in the temperature interval of 300 – 1000°C (shrinkage is about 1.7%). The second segment of shrinkage starts from 1200°C and continues to 1700°C (the total shrinkage reaches 7%).

The properties of ceramics depending on the size of globules and the sintering temperature are given in Table 1.

It is evident that as the globule size decreases and the sintering temperature increases, all traditional modifications of properties persist.

TABLE 1

Ceramic sample	Globule size, μm	Sintering temperature, °C	Bulk density, g/cm^3	Relative porosity, %	Water imperme-ability, μm^2	Compressive strength, MPa
1	< 50	1600	1.38	48.9	0.01	2.2
2	50 – 100	1600	1.37	49.0	0.69	2.2
3	100 – 160	1600	1.41	47.8	13.30	2.1
4	160 – 200	1600	1.42	47.4	24.20	–
5	200 – 315	1600	1.36	49.5	38.40	0.2
6	315 – 400	1600	1.37	49.1	52.40	0.8
7	50 – 100	1650	1.61	40.2	0.24	8.0
8	100 – 160	1650	1.58	41.5	2.27	7.7
9	50 – 100	1700	1.61	40.4	0.08	18.0
10	100 – 160	1700	1.61	40.5	0.57	15.0
11	160 – 200	1700	1.73	35.8	2.23	15.4
12	200 – 315	1700	1.54	43.1	5.25	12.2
13	315 – 400	1700	1.55	43.0	5.94	12.0

As the globule size increases, the density at a constant sintering temperature varies little. However, the water permeability grows and the strength decreases. The modifications of water permeability and strength are determined by the pore size in ceramics, which grows with increasing globule size.

As the sintering temperature grows from 1600 to 1700°C, the bulk density of ceramics grows and the open porosity decreases. It should be noted that a decrease in porosity by 10% decreases the water permeability by an order of magnitude and increases its strength as much.

Thus, a technology for producing ceramics of fibrous and granular structures is developed. The obtained ceramics has high strength and high values of porosity and permeability. Products made of such ceramics can be used as permeable elements in the filtration of various media, including aggressive ones. Ceramics made from granules are suitable for the production of membrane filters.

REFERENCES

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